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SEISMIC STUDIES OF THE ARCTIC OCEAN FLOOR

by

KENNETH HUNKINS

LAMONT GEOLOGICAL OBSERVATORY

Columbia University

PALISADES, NEW YORK

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Scientific Report No. 1

AF 19 (604) 2030

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Geophysics Research Directorate

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Abstract

Reflection and refraction seismic measurements from Drifting Station Alpha in the Arctic Ocean have revealed details of a prominent submarine rise, called the Alpha Rise. This feature trends across the Arctic Ocean subparallel to the Lomonosov Ridge. The minimum depth sounded in its central portion was 1426 meters at 85° 03'N and 171° 00'W. The rise descends to depths of over 3000 meters to the north and south. Sub-bottom reflections reveal a characteristic echo from a depth of several hundred meters below the ocean floor in the eastern area of the rise. This reflection is not pronounced in the western area. The eastern area also has a rougher bottom texture than the western area.

Several short unreversed refraction profiles were made. Dips and strikes of the ocean floor from reflection records aided interpretation. An average of three measurements shows the upper "unconsolidated" layer to be 0.38 kilometers thick. One profile revealed a 2.80 kilometer thick layer of 4.70 km/sec velocity. Below this lay the "oceanic" layer with a velocity of 6.44 km/sec and an undetermined thickness.

Introduction

Reflection and refraction seismic techniques were used to study the Arctic Ocean floor from Drifting Station Alpha during the International Geophysical Year. Reflection measurements were made on a daily schedule from July 1957 to November 1958. Refraction measurements were made during the summer of 1958. The station drifted along an irregular track in the North Canadian Basin under the influence of ocean currents and wind (Fig. 1). The track lies in the area between 83° to 86°N and 115° to 175°W. Position of the station was determined daily by astronomic fixes when cloud conditions permitted. Location was determined to better than 1/2 mile in most cases. The bathymetry of the Arctic Ocean in this area, the various types of sub-bottom reflections and the refraction studies of the sediments are discussed in this paper.

Acknowledgments

This work was carried out under Contract No. AF 19 (604) 2030 from the Geophysical Research Directorate of Air Force Cambridge Research Center. Assistance in the field work was provided by Maurice Davidson, Franz van der Hoeven, Gary Latham, and Bryan Isaaks, all of Lamont Geological Observatory. Other scientists and Air Force personnel as well as the air force station commanders gave valuable cooperation and assistance. Discussions with Dr. Jack Oliver, director of the Arctic geophysics project at Lamont, were invaluable in analyzing and interpreting the results.

Instrumentation

The recording instrument for all the work was a Houston Technical Laboratory 7000-B seismograph with twelve amplifiers. The signals from an array of twelve geophones were recorded photographically on dual channels. The upper twelve traces on the record are at high gain. The lower twelve traces duplicate the upper set at one-half the amplitude. Three paper speeds were available: 6.6, 13 or 32.4 inches per second. The amplifier response is relatively flat from 5 to 500 cycles per second. The camera and amplifiers were operated in the laboratory hut and connected to the geophones outside by cable. Electro-tech model EVS-2B vertical geophones, with a natural frequency of 14 cycles per second and 0.53 critical damping, were used. They were placed firmly on the ice surface. A right angle array was used with six geophones on each line. For reflection work, two different shot positions with respect to the array were used (Fig. 2). The change from the first to second arrangement was made in May 1958 when the camp had to be moved to a new ice floe. The second shooting arrangement allowed reflection computations to be made more easily. True orientation of the array was determined from the daily astronomic shots. The timing tuning fork was checked periodically against a chronometer which had been rated against WWV radio time signals. During all shooting, the camp electrical generators were shut down to prevent mechanical and electrical noise pickup.

Reflection Studies

Vertical reflection soundings were made daily during the winter and twice daily during the summer. Since the average drift of the floe was 3 1/2 miles per day, these soundings are usually spaced from one to four miles apart along an irregular track. Unusual calm or windy periods resulted in closer or wider spacing. The sounding positions are interpolated between astronomic fixes and are in most cases accurate to one-half mile. During periods of persistent cloud cover, several days may pass between fixes and the accuracy of the sounding position may drop to one or two miles.

For the reflection shots, one-quarter pound charges of dynamite were exploded at a depth of 10 feet below the water surface. Firing was done electrically and the cap break was recorded. A short pulse blaster insured that the cap did not fire late. The delay between the electrical impulse and cap detonation was found to be 0.0025 seconds. Correction was made in the computations for this delay. The recording paper was run at a speed of 13 inches per second for the early part of the record. After about two seconds the speed was manually increased to 32.4 inches per second in time to record the reflections at high speed. This method conserved photographic paper but gave fine detail in the reflection portion of the record. Two sounding records were usually made in quick succession, the first with automatic gain control and the second with linear amplification.

Bottom Reflections

The array of geophones allowed the dip and strike as well as the depth of the bottom to be found. A total of 623 sonic soundings were made, and, of these, 555 yielded dip and strike information. Calculation of the dip and strike was made using standard formulas (Nettleton, 1940). Straight line ray paths were assumed. The measured dips and strikes represent the attitude of a portion of the ocean floor one-half the length of the spread on each side, that is, 500' x 500'. Dip of the bottom ranged from 0° to 22°. The average dip was 2.70° with a standard deviation of 2.25°. The frequency distribution (Fig. 3) shows that most dips lie between 1/2° and 1 1/2°. The depths represent the slant distance to the nearest reflector and are accurate to less than one meter. Sound velocity corrections to the depth measurements were made with Matthew's tables (1939). Wire soundings taken at Station Alpha are in close agreement with the sonic soundings.

Paper speeds were high enough to permit determination of the initial trace motion for reflections. All bottom reflections observed were compressional or positive; they appear to indicate in all cases that the characteristic impedance (density x sound velocity) of the top-most sediment is greater than that of water. The frequency of the first bottom reflection is roughly 400 cycles per second, measured peak to peak on the record. Thus the wavelength in water is about 3 1/2 meters. If any sediment layer with an impedance less than water exists, it probably has a thickness less than about four meters.

Throughout its occupation, Drifting Station Alpha sailed over a submarine feature which has been named the Alpha Rise after the station. At the beginning of operations, the station was immediately south of the rise in over 3000 meters of water. The maximum depth recorded was 3871 meters at 82° 48'N and 167° 01'W. The northward movement carried the station over the rise at almost right angles to its trend. After a northernmost point of 85° 32'N and 171° 10'W was reached, the station moved southward nearly retracing its previous track. The station then turned northeastward and moved nearly along the trend of the rise. Near the end of the occupation of the station the shallowest depth of 1140 m was recorded on the eastern end of the rise at 86° 09'N and 114° 08'W.

The drift of Station Alpha provided detailed bathymetry for several areas of the rise (Fig. 4). The bathymetric chart was contoured with the aid of dips, strikes and depth information. The broad outline of the Alpha Rise was known previously from the drift of Russian station NP-4 and from soundings of the High Latitude Aerial Expeditions (Bathymetric Chart of the Arctic Ocean, as of 1956 approximately; Hope, 1959). It trends northeast-southwest across the Arctic Ocean from the edge of the shelf north of Wrangel Island to the shelf off Ellesmere and Axel Heiberg Islands. The Alpha Rise is sub-parallel to the Lomonosov Ridge and is twice as broad as that feature or about 200 kilometers wide. It is shallower than present maps indicate. A minimum sounding over the central portion of the rise was 1426 m at 85° 03'N and 171° 00'W. To the north and south of it lie basins with depths over 3000 meters. The dip information and bathymetric profiles show that the topography of the rise is rugged (Fig. 5). The profiles strongly suggest that this is an area of fault block mountains. The Alpha Rise is not tectonically active at the present time since it lies in an aseismic area of the Arctic Ocean (Gutenberg and Richter, 1954).

Topographic Echoes and Sub-bottom Reflections

Several bottom echoes or topographic echoes are present on many records. They occur in areas of rugged topography where several reflectors return echoes from different locations (Plate 1). Characteristically, the first reflection is low in amplitude and shows steep dip since it comes from a topographically elevated area having a little reflective area. The principal bottom echo arrives shortly after and is of greater amplitude and flatter dip. The topographic echoes can be identified by their high frequency content. Sub-bottom echoes suffer high frequency attenuation in the sediments and have a lower frequency composition.

Sub-bottom reflections are present on the majority of the reflection records. They occur as lower frequency events after the bottom reflection. The quality of these reflections was high, good reflections being obtained with linear amplification and no filtering (Plate 2). The level, stable ice floe, lack of background noise and low attenuation of sound in water all contribute to the good reflection quality.

No confusion between sub-bottom reflections and second bottom reflections was encountered since the water was deep enough that the second bottom reflection arrived after the deepest sub-bottom reflection. However, bubble pulses produce some undesired complications in the records. The reflection shots produced a bubble pulse which appears at 0.09 to 0.11 seconds after the main explosion. This pulse produces a duplication of sub-bottom echoes but allowance was made for this when interpreting the records.

The records were classified by a system similar to that used by Hersey and Ewing (1949). Records with multiple bottom echoes or topographic reflections are of Type T. Those showing only one strong sub-bottom reflection, or possibly several weak reflections and one strong reflection, are Type M. The Type M reflection frequency is usually 50 to 100 cycles per second measured peak to peak on the record and often has a larger amplitude than the bottom reflection (Plate 2). A sediment velocity of 2 kilometers per second is assumed in computing depths of reflections. This makes the two-way time in milliseconds equal numerically to the depth in meters of the reflector below the bottom. Where several sub-bottom reflections of about the same amplitude are present, the record is of the structural or S type (Plates 3 and 4). Records with no coherent sub-bottom reflections are reverberation or R type (Plate 1). Type R records may indicate either a lack of deep acoustic reflectors or confusion of sub-bottom reflections by rough topography. Although type

R records occur in areas of both low and high relief, it is only in areas of low relief that it can be said that reflectors are lacking. Either M, R, or S records may also be T type records (Plate 5). The type T record is a good index to rough bottom texture.

It is evident from the map of reflection types (Fig. 6) that all these reflection types were found on the Alpha Rise. Only the type R and T records are strongly correlated with bottom dip, being found on the steepest slopes. Type M and S records are both found on all but the steepest slopes, but are usually best developed in level areas. The most striking feature of the reflection distribution is the contrast between the eastern and western crossings of the Alpha Rise. On the western crossing, type S reflections are principally seen with few topographic echoes. The oblique eastern crossing produced principally type M-T records. This variation in record type cannot be due to instruments or technique since the same instruments and shooting technique was used for all the field work. It must indicate a stratigraphic or structural difference between the eastern and western ends of the Alpha Rise. The type T records show that bottom texture is rougher in the eastern area. The M reflection in the eastern area probably corresponds to the "second reflection" observed by Crary and Goldstein (1957) from T-3 in the area from 84° to 88°N and from 70° to 100°W. This "second reflection" lies from 210 to 340 m below the bottom. It is likely that the type M reflections found on the eastern Alpha Rise by Station Alpha continue eastward to the area mapped by T-3. The strong type M echo indicates a good impedance contrast. It is quite possible that this reflection represents in some cases the base of the unconsolidated sediments in areas where there is a strong impedance contrast between these sediments and the underlying rock. In the western area, where a single strong reflection is absent, it may be that the impedance contrast at the base of the sediment is low due to a different underlying rock which has properties little different from the overlying sediment. The reflections of the type S record would, if this were the case, be due to layering within the unconsolidated sediment.

Refraction Studies

During the spring and summer of 1958, five unreversed refraction stations were made at Drifting Station A. Of these stations, only the last three recorded the refracted ground wave as a first arrival. Only these three stations are discussed here. For the refraction work, explosives were sledged and back-packed to locations on the ice where they were detonated. The various arrivals were recorded by the HTL 7000-B seismograph at the camp. The difficulties of crossing pack ice with its many open leads and hummocks prevented long refraction shots using this technique.

The charges ranged from 25 to 75 pounds of TNT fired about five to eight feet below the water surface. In all cases the charges blew out preventing bubble oscillations. The arrivals were recorded on a right angle array of 14 cycles per second geophones. This array permitted the measurement of the apparent velocities and azimuths of the arrivals. Recording speed was 6.6 inches per second. Attempts at wire and radio communication were unsuccessful and time breaks were not recorded.

Distance from the shot point to the receiver was determined indirectly using the air and water arrivals which were respectively detected with a microphone and hydrophone. The relationship

$$t = r/0.33 - r/1.44$$

was used to find the distance, r, in kilometers where t was the time difference in seconds between the direct water and air arrivals. This method is approximate and an error in distance of up to 5% may result from uncertainties in the air and water velocities used.

Depth of water beneath the receiver was measured by vertical reflection at the time of the refraction shot. This reflection record gave the depth, dip and strike of the bottom as well as of sub-bottom layers when present. Other reflections were taken in the vicinity of the profile when the drift of the station allowed. These showed the bottom to be quite irregular at all the stations. The measured dips are apparently only of local significance. For this reason, the apparent velocity of the refracted wave across the array was corrected, using the dip of the bottom and sub-bottom beneath the receiver. However, all interpretation was made with the assumption of horizontal bedding between the shot point and receiver. This was considered justified since depths were irregular but did not deviate widely.

In making the interpretations, straight line ray paths were assumed. Also assumed was an upper layer with a velocity of 2 km/sec. No direct evidence of this layer was seen in the refraction work since it would be masked by the water layer at all the stations. However, from previous work it seems reasonable to assume such a layer with an average velocity of 2 km/sec for depths on the order of 0.5 km (Crary and Goldstein, 1957; Nafe and Drake, 1957). All structural interpretations apply to the area immediately below the receiver. The notation for the various arrivals is that of Ewing and Ewing (1959) with the addition of the symbol "A" for the direct air wave.

Refraction Profile No. 3 (Figs. 7 and 8) On July 25, 1958, a refraction station was made which consisted of two shots at distances of 2.36 and 7.19 km. The ocean bottom beneath the receiver was at a depth of 2085 m, with a dip of 6°. The apparent dip in the line of the shot was 4° away from the shot. R_1 and R_2 indicate that the depth along the profile is somewhat less than that under the receiver but this latter depth was used for computations. The apparent velocity of the refracted wave in the line of the shot was 4.4[illegible] and 4.33 km/sec. These values were corrected for dip to 5.52 and 5.41 km/sec. The interpreted structure section shows 2085 m of water underlain by 0.48 km of sediment with a velocity of 2 km/sec. Below this lies an undetermined thickness of 5.52 km/sec material.

On several reflection records taken in the vicinity, a type M sub-bottom reflection appears. The depth of the horizon below the bottom is noted in parentheses in Figure 8. This depth assumes a sediment velocity of 2 km/sec. In the vicinity of the profile, the depth to the horizon is about 200 m. Thus this prominent reflector apparently lies above the base of the layer of low velocity sediment.

<u>Refraction Profile No. 4</u> (Figs. 9 and 10) A profile of three shots was made on 2 August 1958. These were at distances of 2.90, 8.26 and 9.18 km from the receiver. The vertical reflection record at the receiver showed 1813 m of water and a bottom dip of 2°. A sub-bottom reflection at 342 m was also shown. This sub-bottom horizon dipped more steeply than the bottom and its dip was used to correct the apparent velocity of the refracted wave. The low-angle reflections indicate high topography between the closest shot point and the receiver. The apparent velocity across the spread in the line of the shot was 5.30 km/sec. This was corrected to 4.70 km/sec by a 2° apparent dip. The interpreted structure is 1813 m of water, a 2 km/sec layer which is 0.37 km thick underlain by an undetermined thickness of 4.70 km/sec material.

The prominent reflection horizon is at 342 m at the receiver site and around this site it is in the vicinity of 350 m. This agrees closely with the 370 m thickness of the 2 km/sec layer found by refraction. Apparently this prominent reflector is the base of the upper low velocity sediment in this area.

<u>Refraction Profile No. 5</u> (Figs. 9 and 11) A profile consisting of one shot at a distance of 11.38 km was made on 3 August 1958. On this record, G_1 is too low in amplitude for its apparent velocity to be determined. Since this station is very close to profile 4, it is assumed that this is the 4.70 km/sec layer. G_2, G_3 and G_4 are all recorded with

good amplitude. The apparent velocities of these arrivals are 5.74, 6.01 and 6.05 km/sec respectively. The corrected velocities, using the dip of the sub-bottom horizon, are 6.44, 6.74 and 6.79 km/sec. These arrivals are apparently from the "oceanic" layer. Interpretation of the results shows 0.29 km of 2 km/sec sediment and 2.80 km of 4.70 km/sec material. Below this lies the 6.44 km/sec layer of unknown thickness. Here the prominent sub-bottom reflection is at a depth of 377 m beneath the bottom at the receiver site. Here the reflector is apparently below the base of the layer of low velocity sediments.

Conclusions

The Alpha Rise is one of the large positive features of Arctic Ocean topography and must be considered in any discussion of the tectonics or physical oceanography of this region. Relief on the rise is rugged and is apparently the result of block faulting. Although only three short refraction profiles were made, they tend to show results similar to those in the North Atlantic Ocean (Ewing and Ewing, 1959). The average thickness of the upper or "unconsolidated" layer was 0.38 km as compared to the 1/2 to 1 km in the North Atlantic. A single measurement of 2.80 km thickness was made for a 4.70 km/sec layer. The "oceanic" layer velocity was 6.44 km/sec which is in close agreement with the velocity of about 6.5 km/sec found in the North Atlantic.

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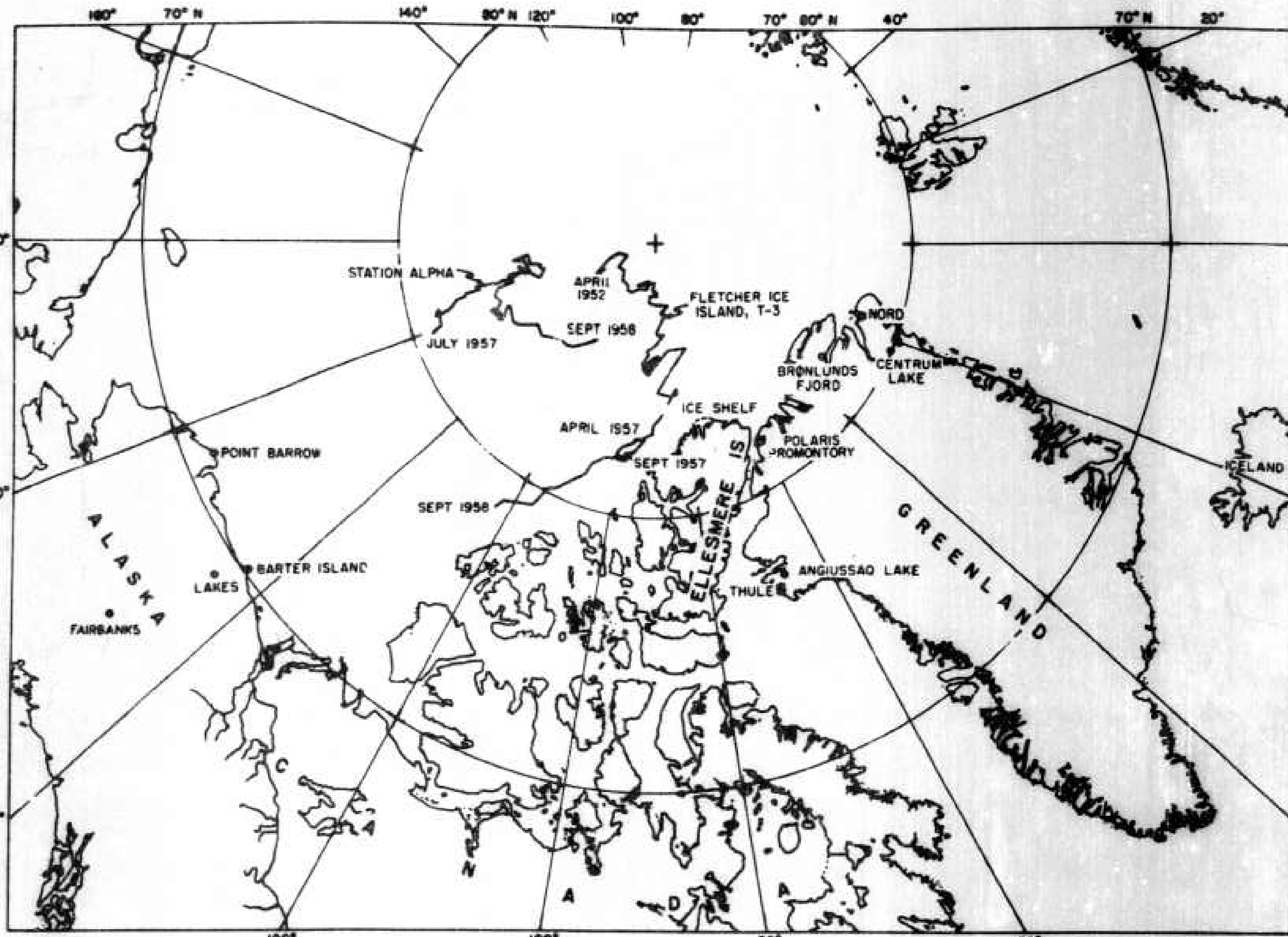


Fig. 1 Track of Drifting Station Alpha in the Arctic Ocean

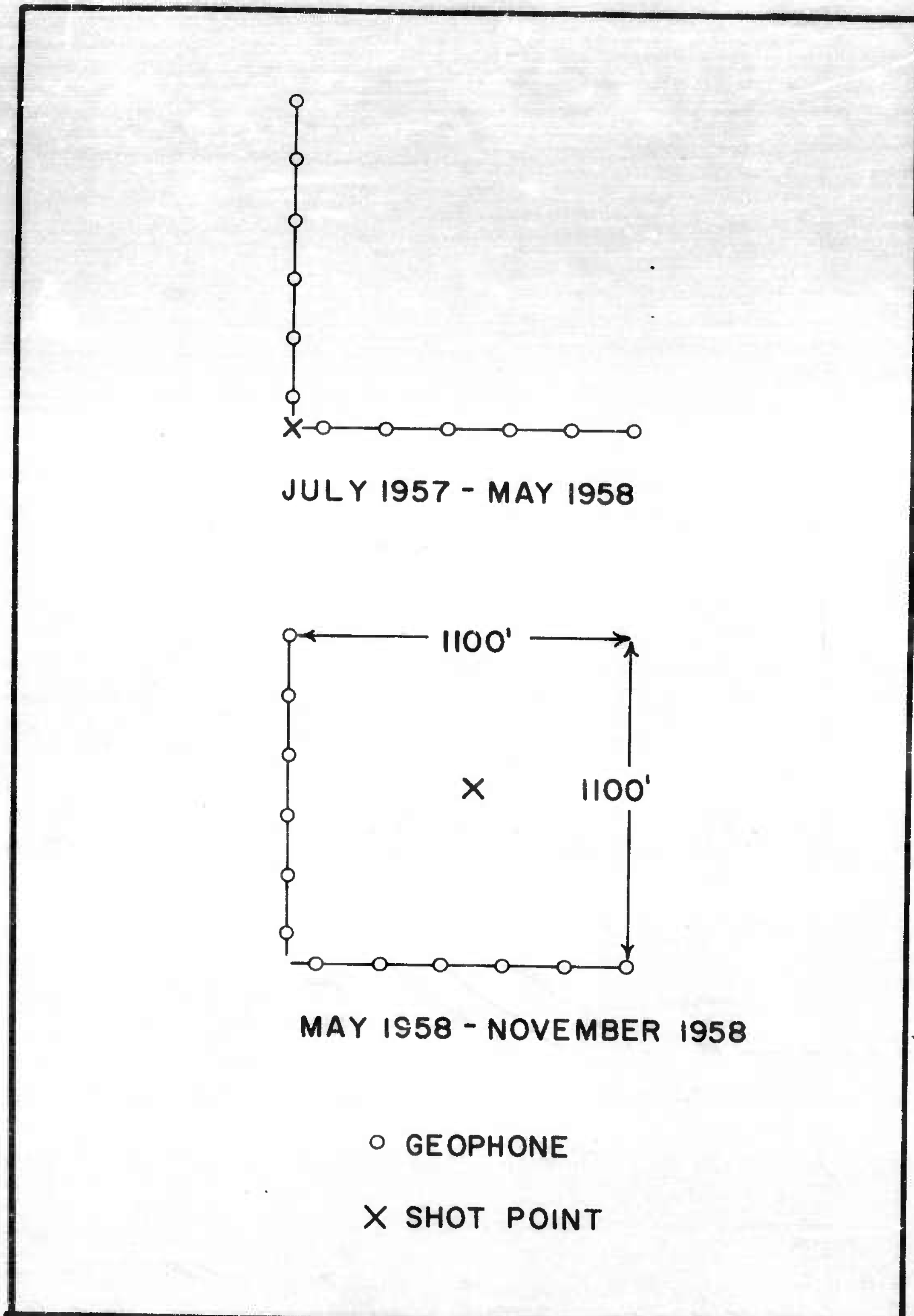


Fig. 2 Arrangement of geophone spreads

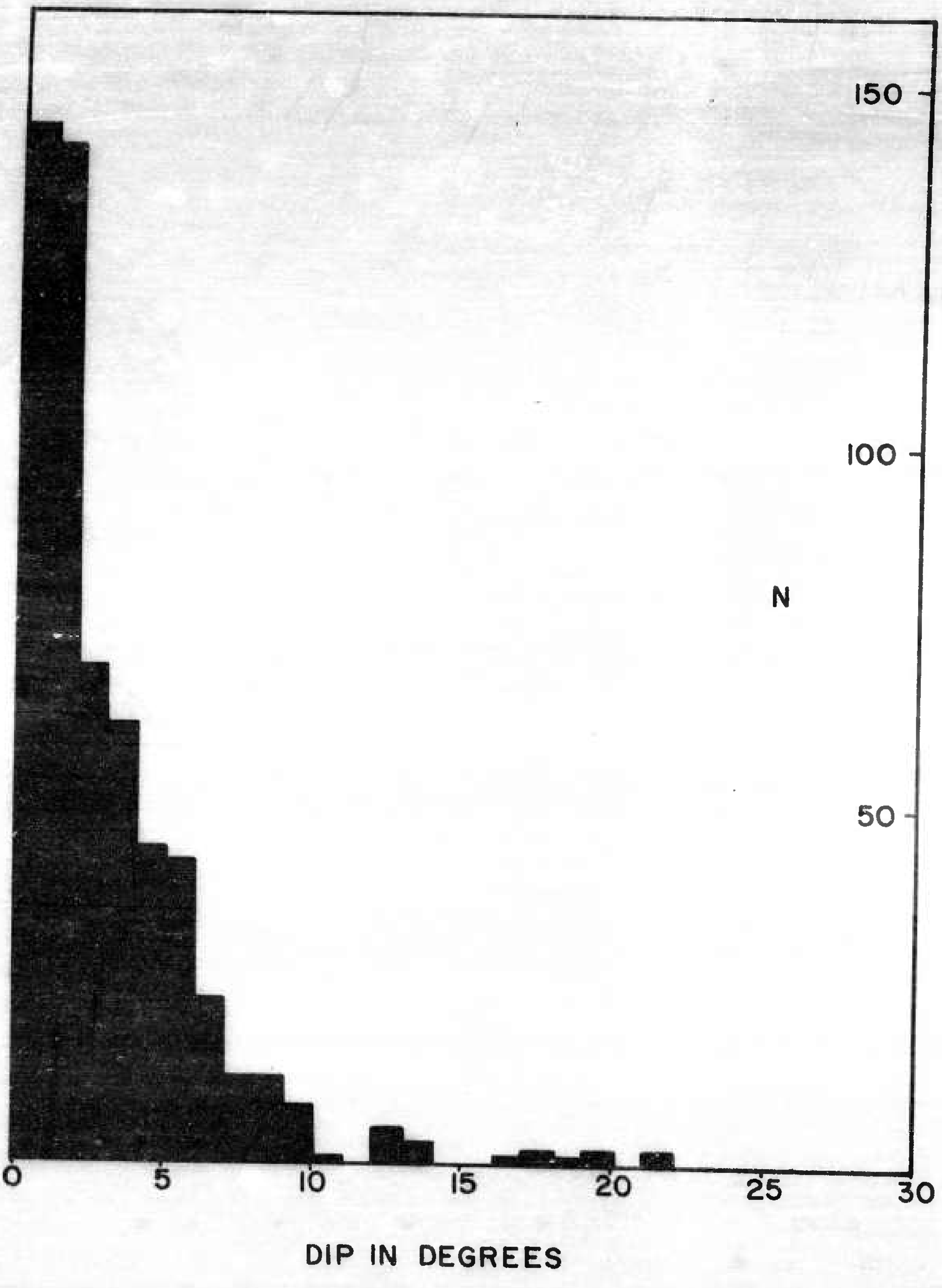
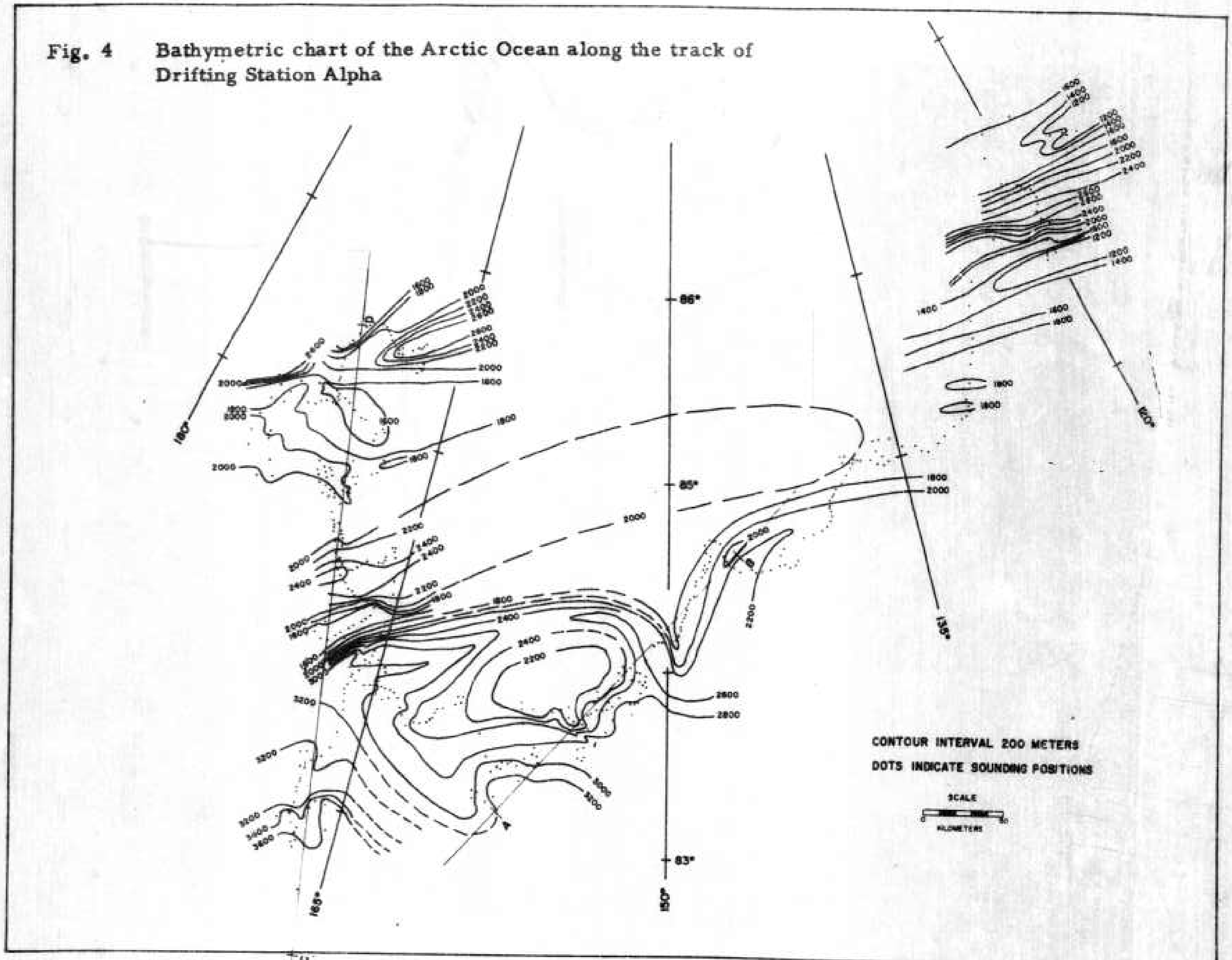


Fig. 3 Frequency distribution of measured ocean bottom dips

Fig. 4 Bathymetric chart of the Arctic Ocean along the track of Drifting Station Alpha



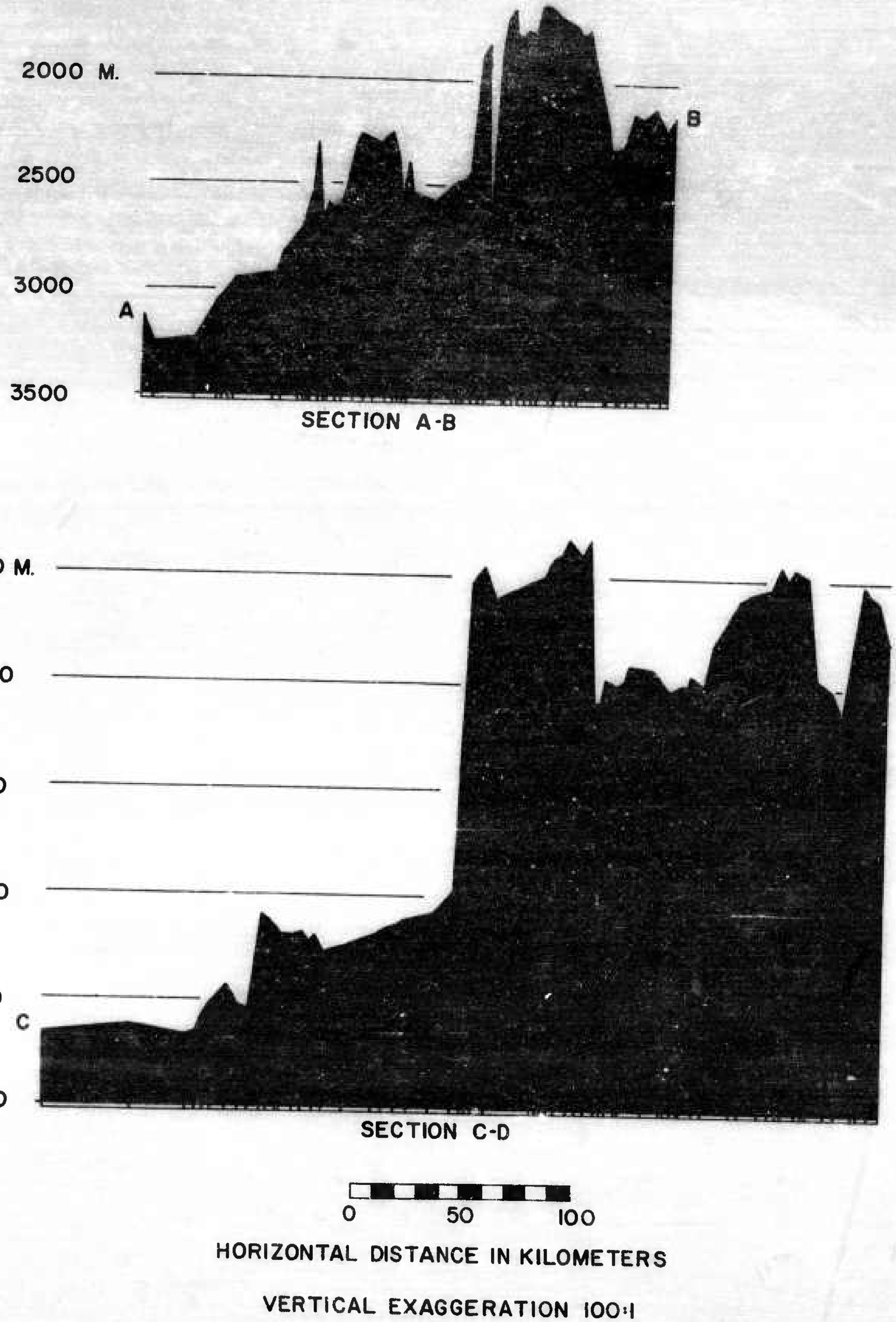


Fig. 5 Bathymetric profiles across the Alpha Rise

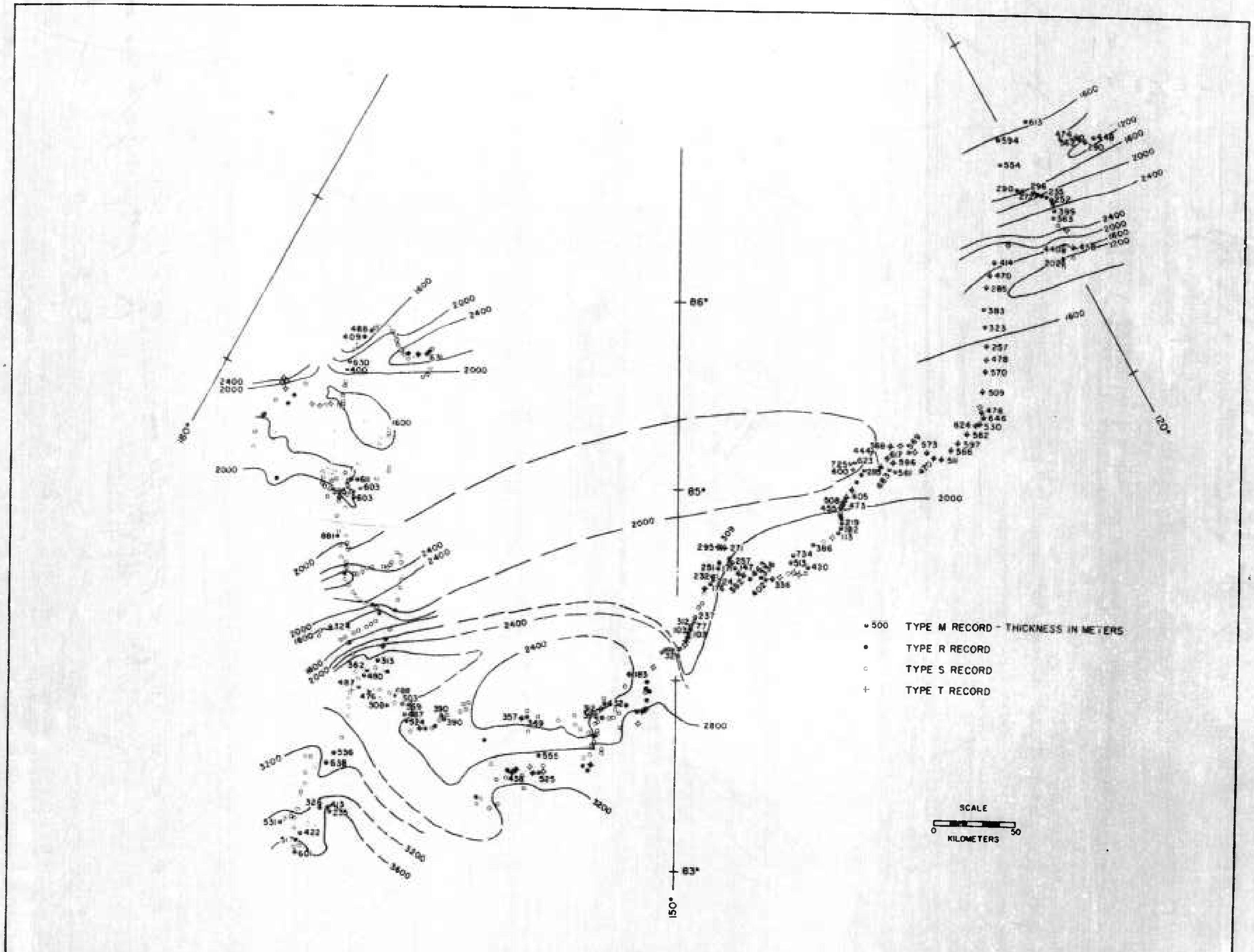


Fig. 6 Map showing types of reflection records observed

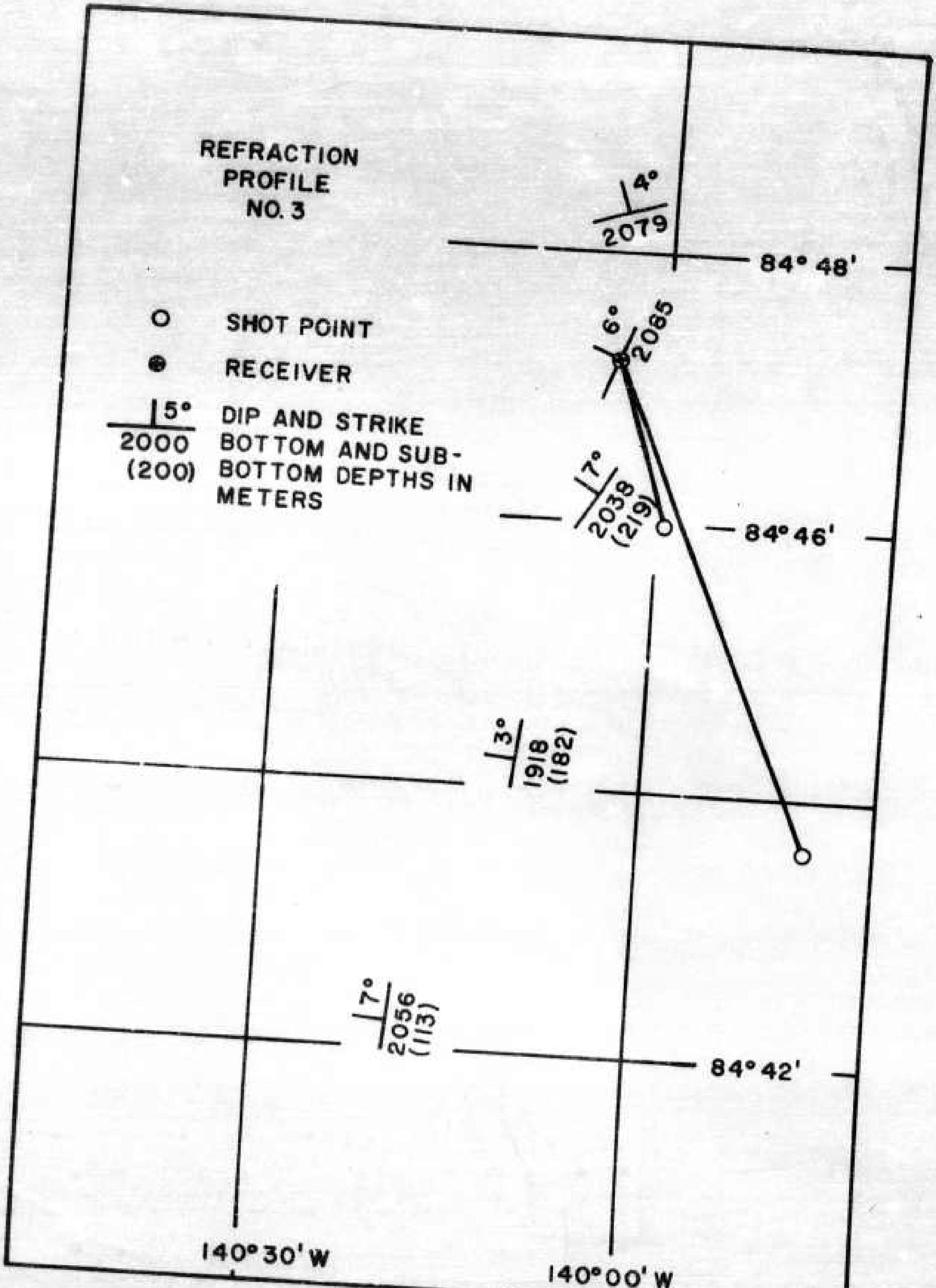
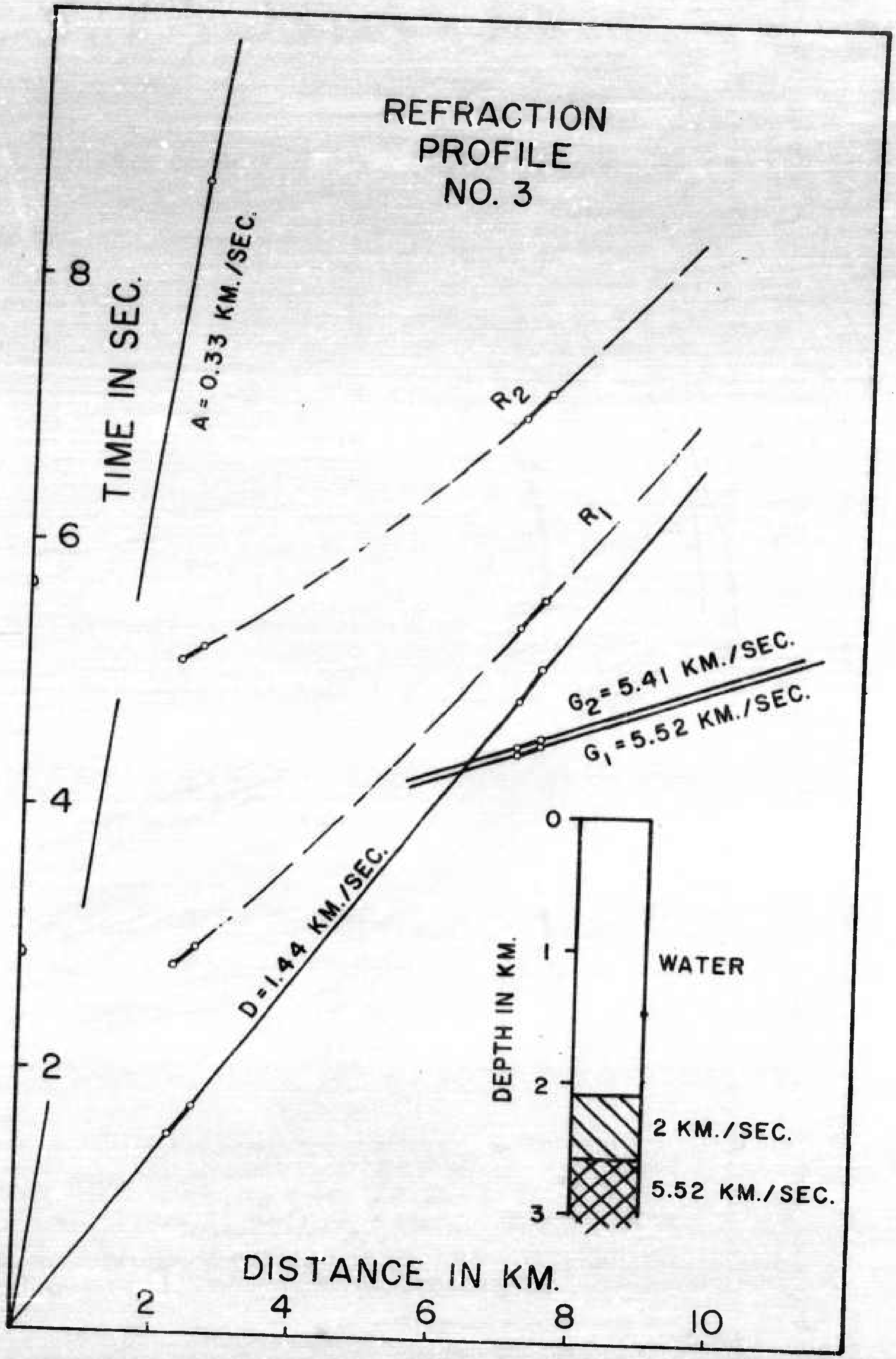


Fig. 7 Map of refraction profile No. 3

Fig. 8 Travel time curves and interpreted structure section for refraction profile No. 3



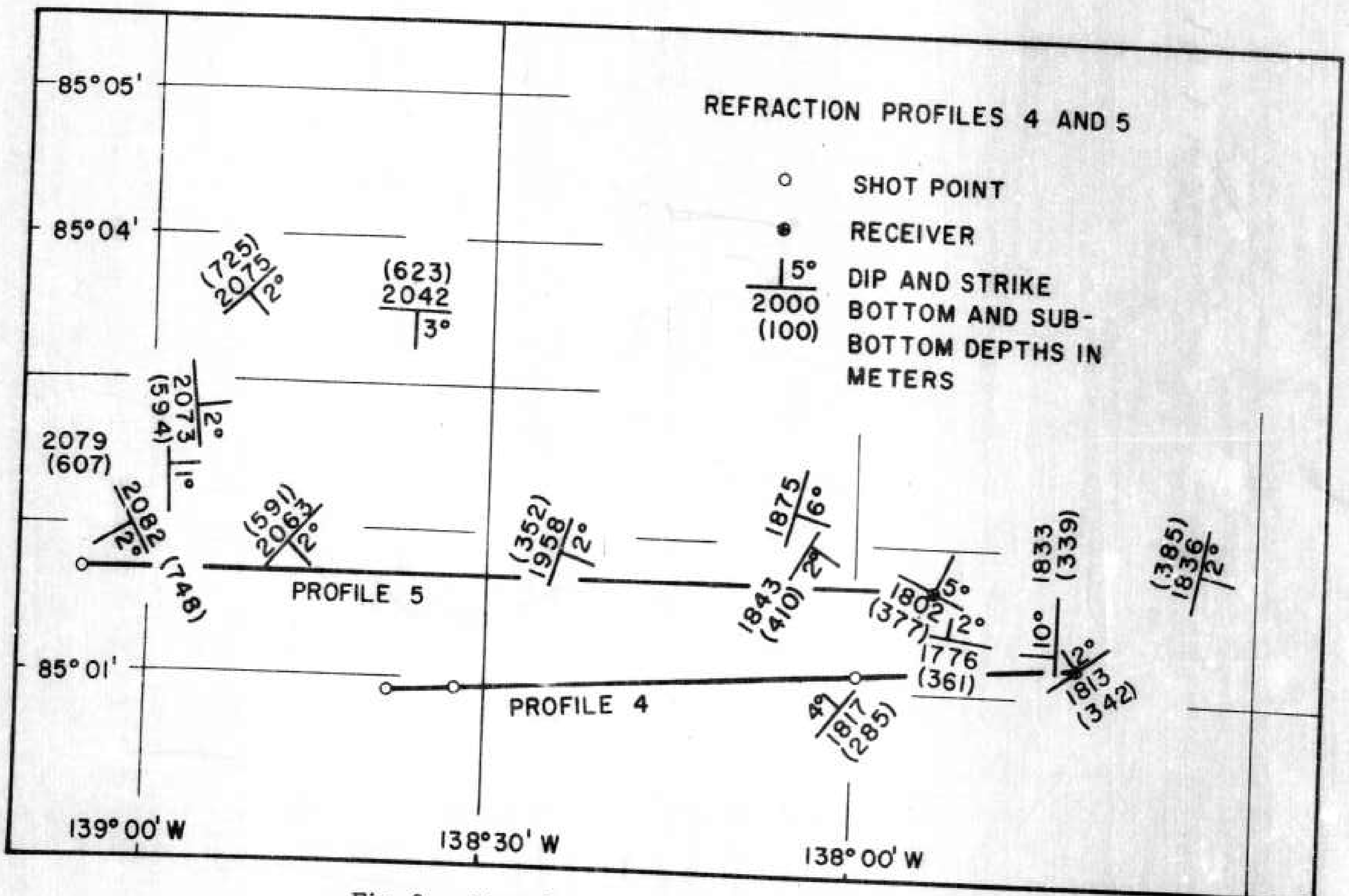


Fig. 9 Map of refraction profiles Nos. 4 and 5.

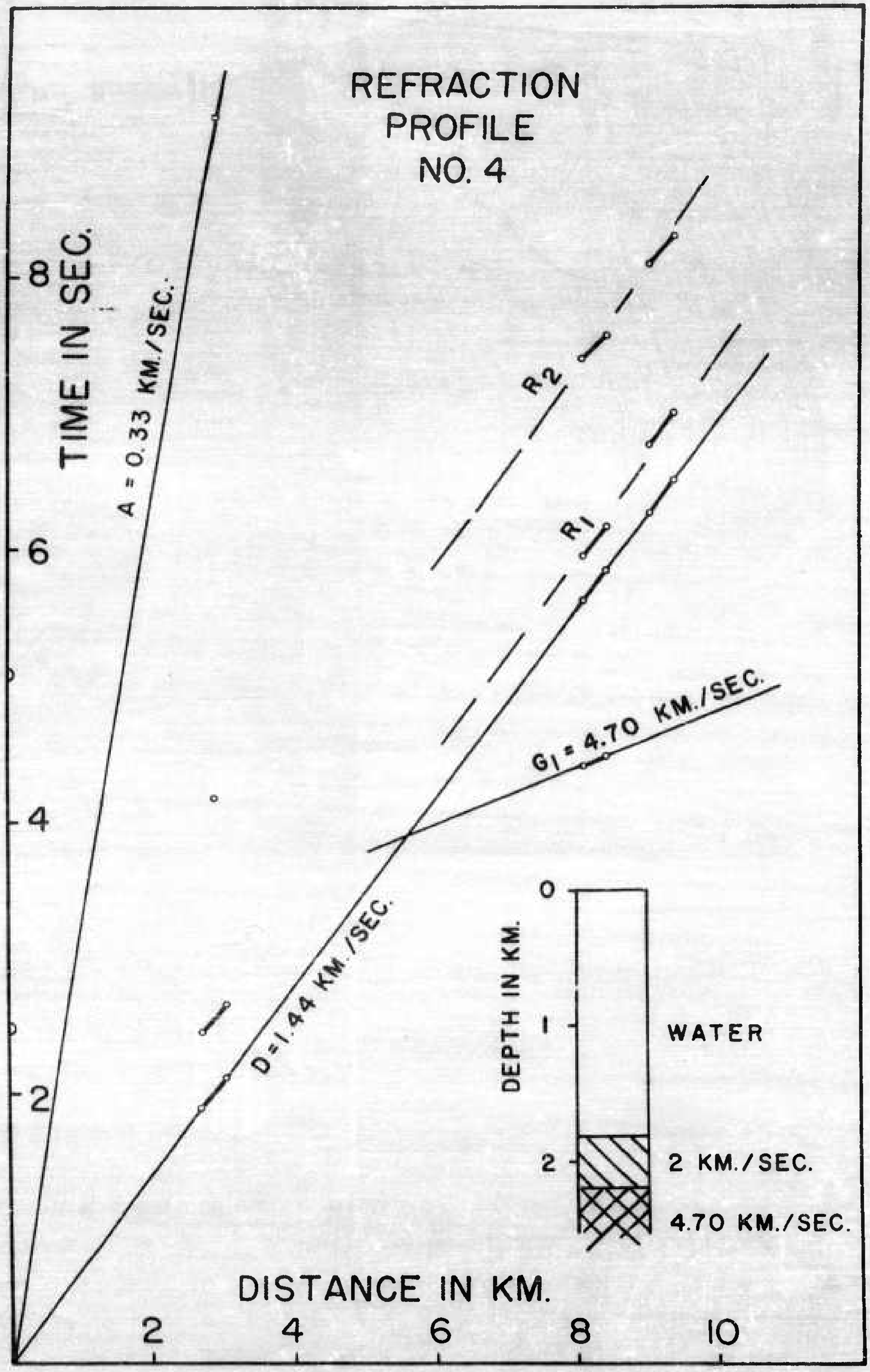
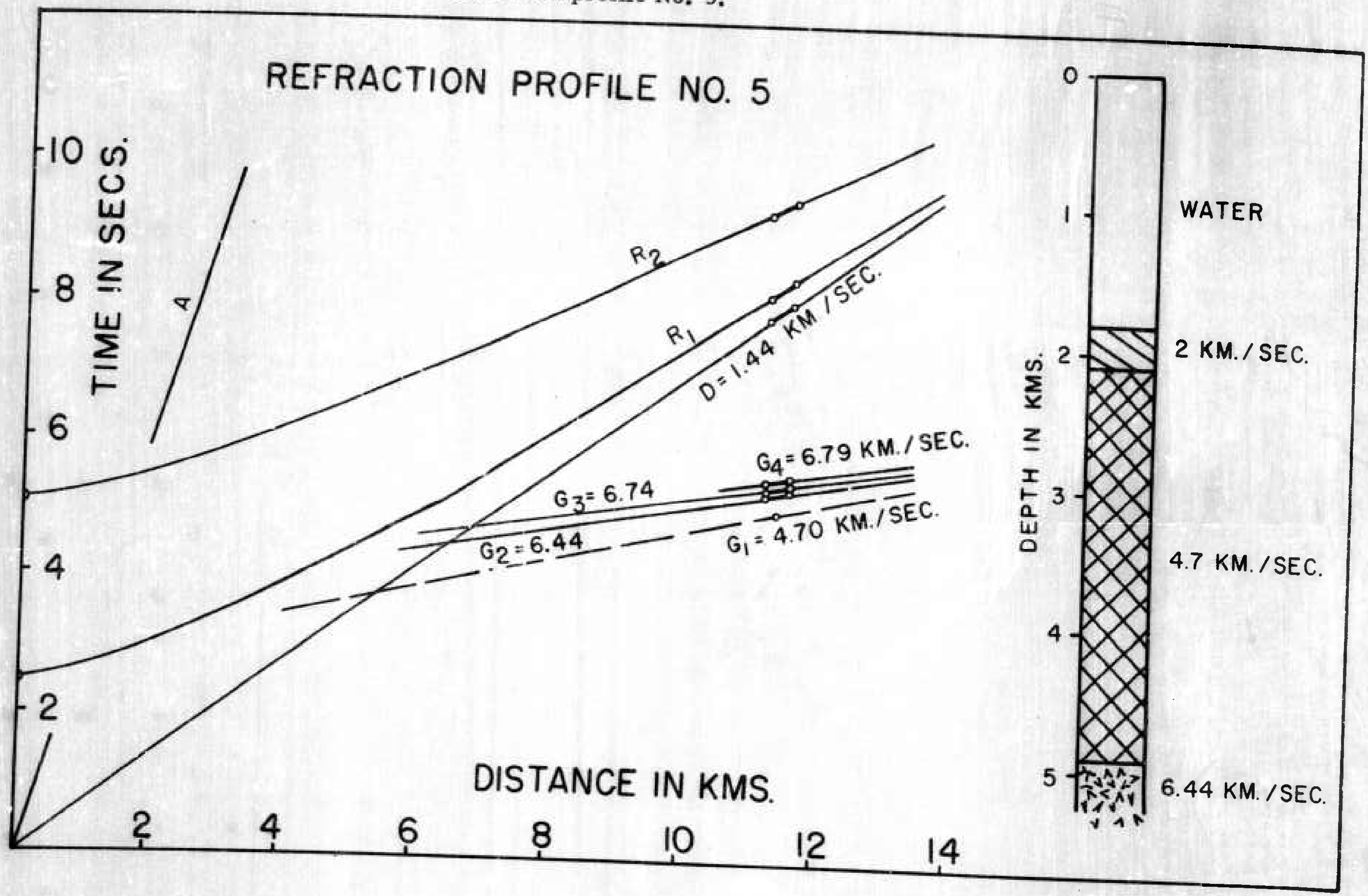


Fig. 10 Travel-time curve and interpreted structure section for refraction profile No. 4.

Fig. 11 Travel-time curves and interpreted structure section for refraction profile No. 5.



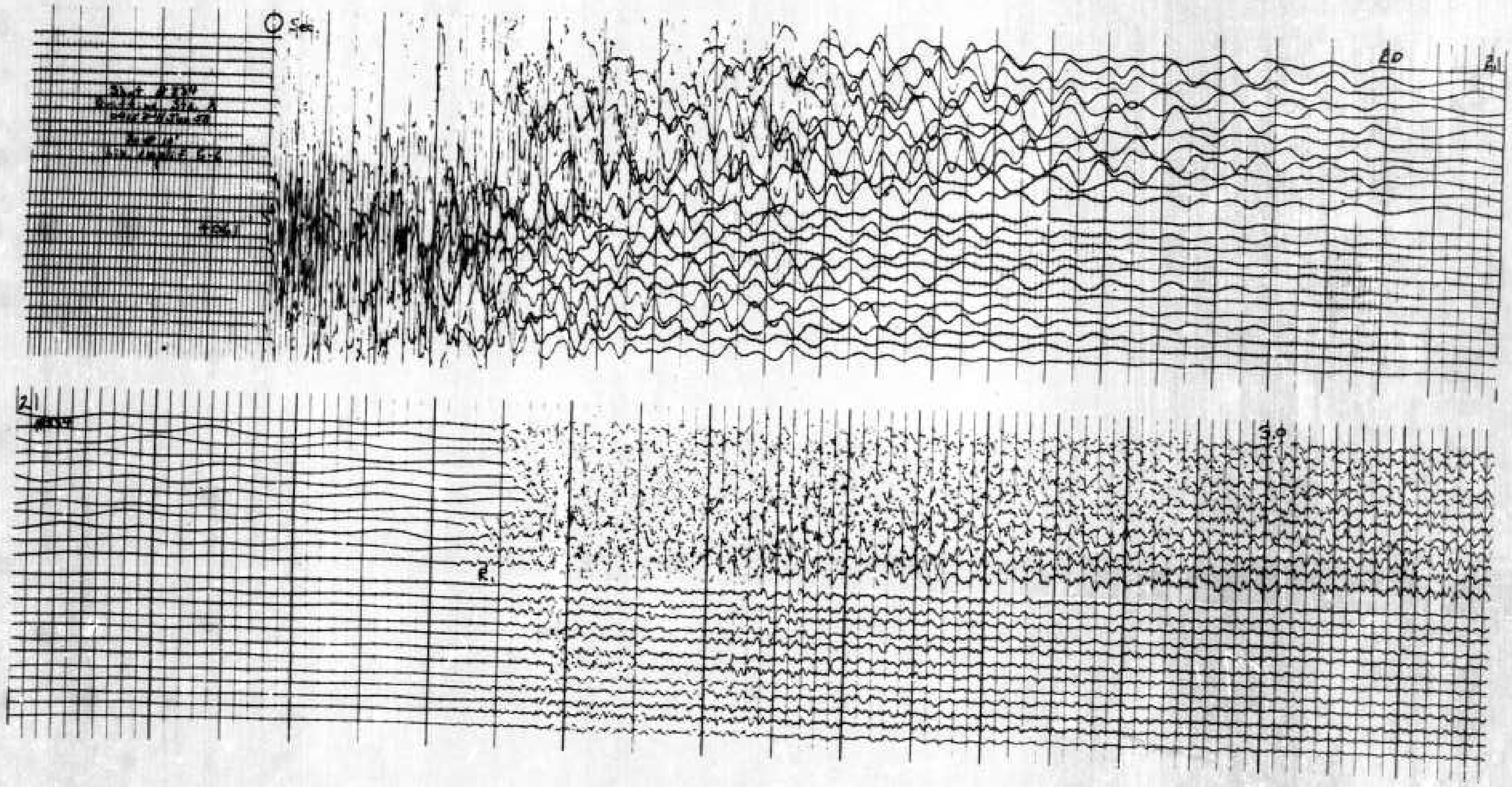


Plate 1 Type R-T reflection record. 84° 11.0'N, 149° 26'W 2556 m. Linear amplification. No filters.

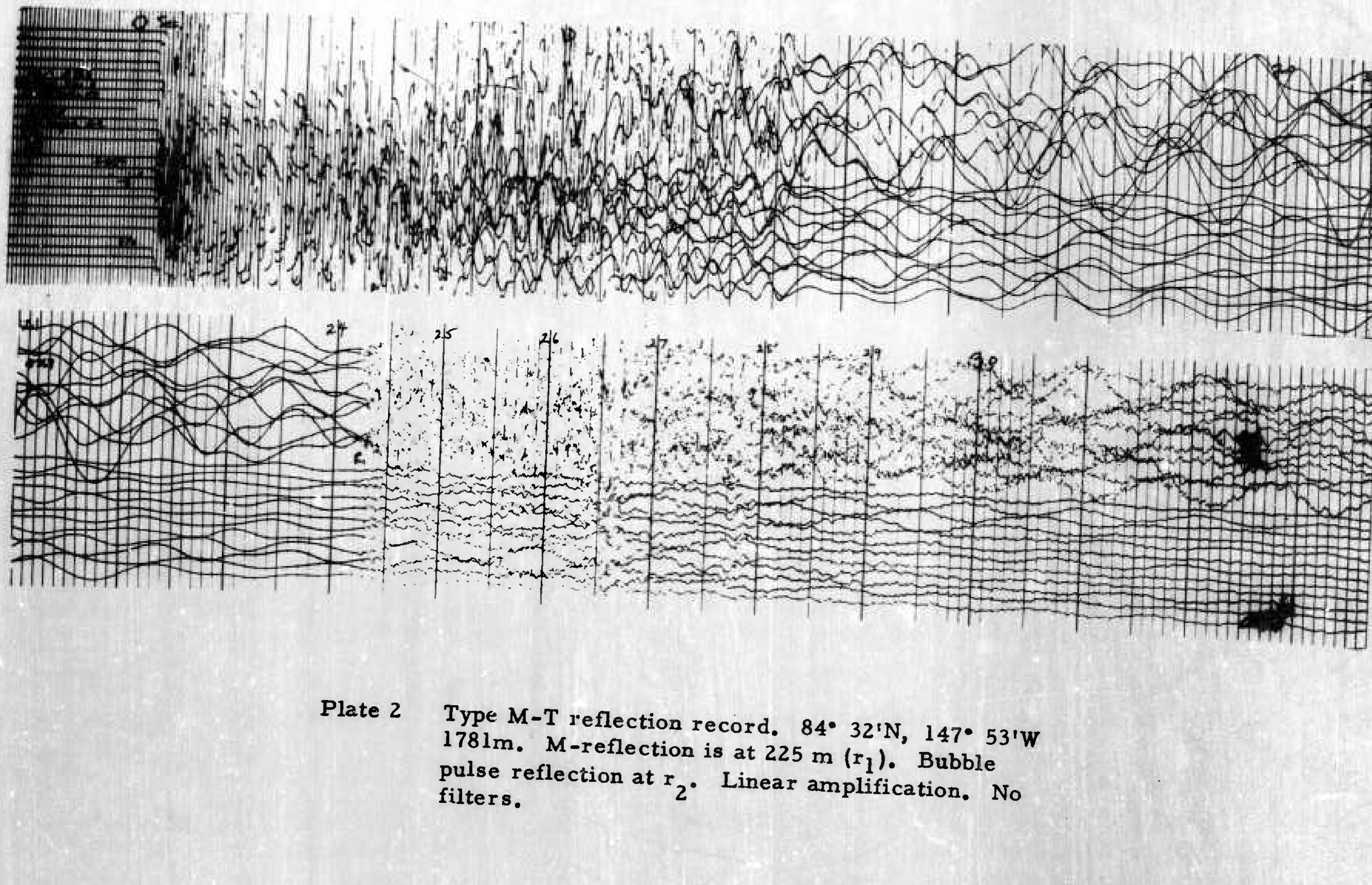


Plate 2 Type M-T reflection record. 84° 32'N, 147° 53'W 1781m. M-reflection is at 225 m (r_1). Bubble pulse reflection at r_2. Linear amplification. No filters.

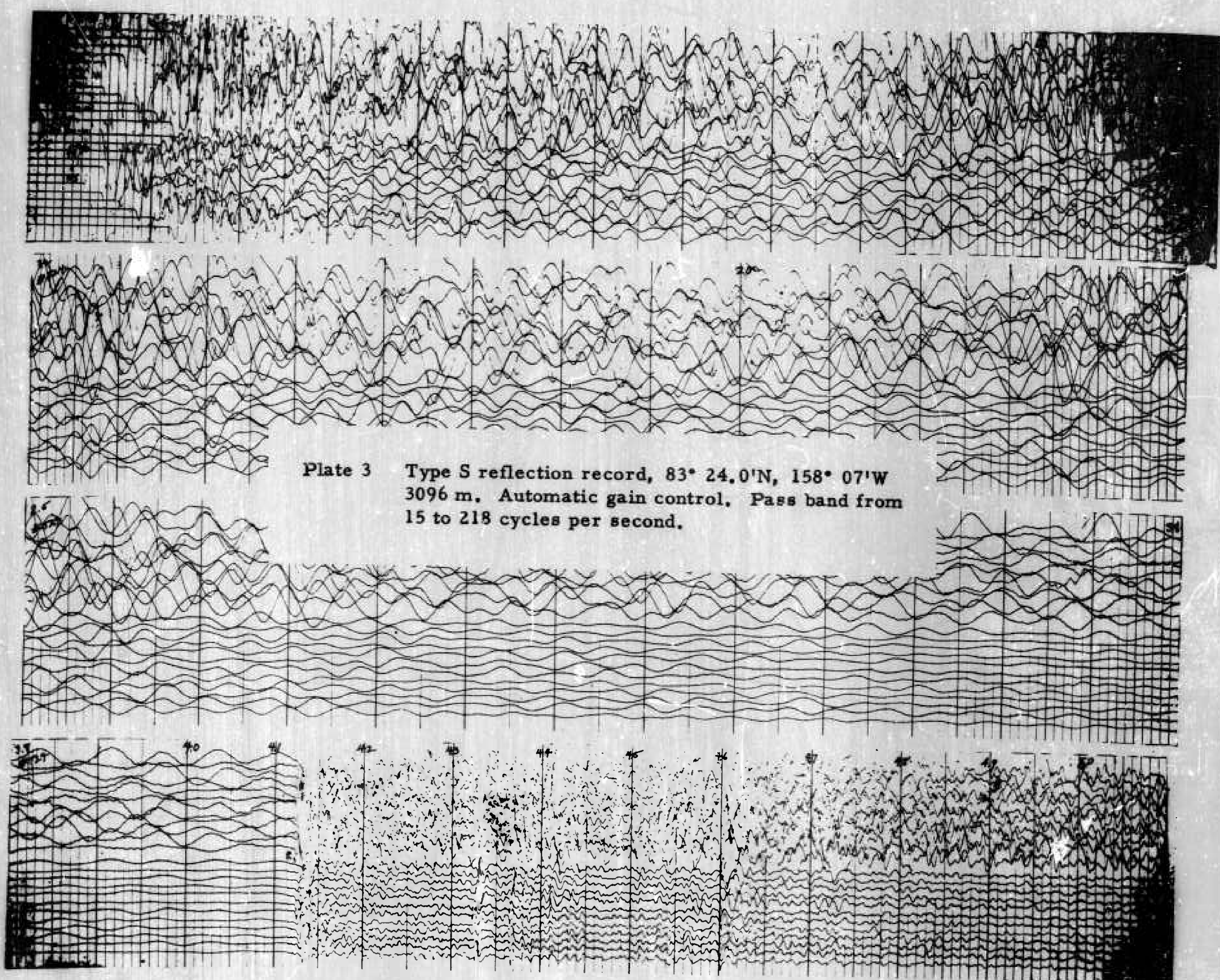


Plate 3 Type S reflection record, 83° 24.0'N, 158° 07'W 3096 m. Automatic gain control. Pass band from 15 to 218 cycles per second.

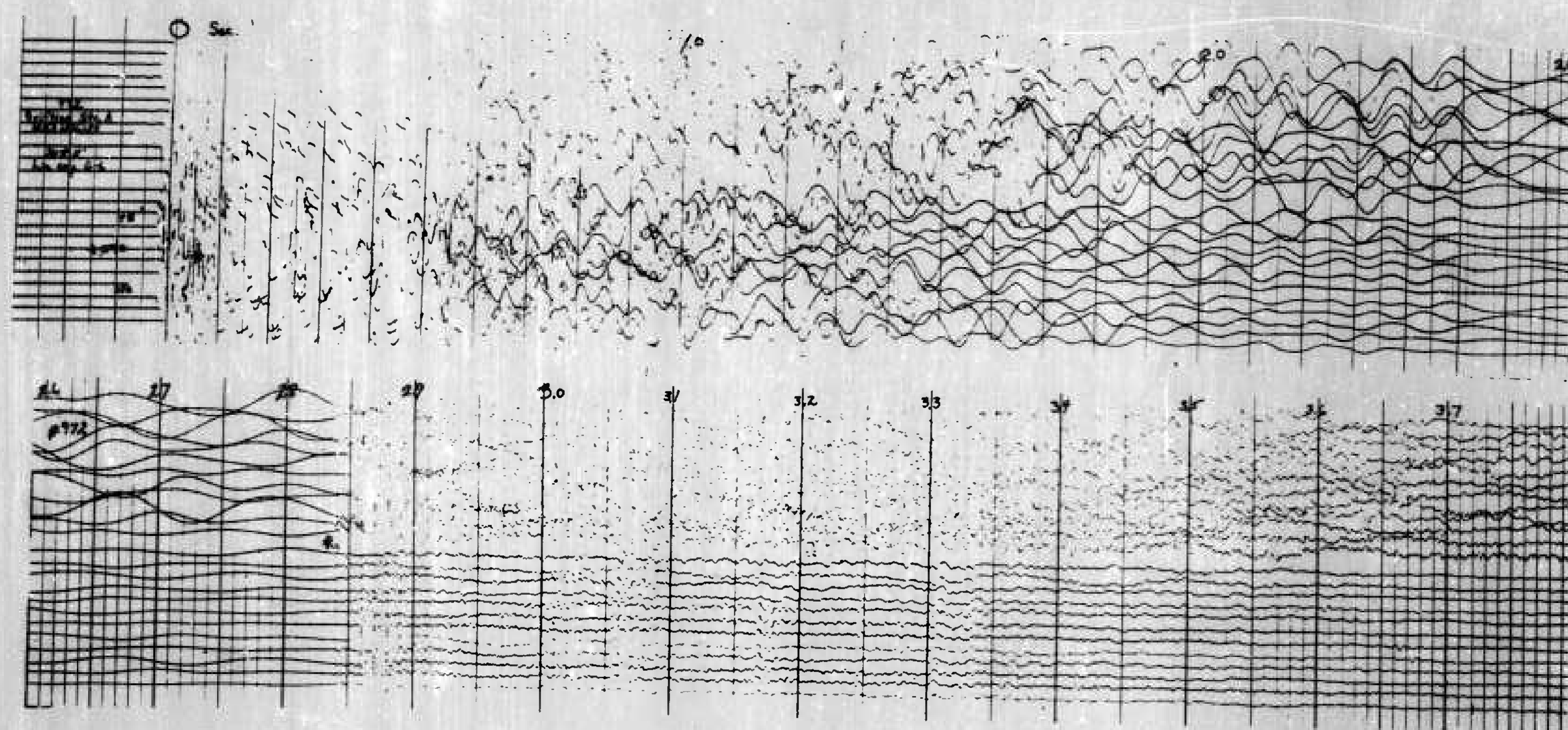


Plate 4 Type S-T reflection record. 84° 31.0'N, 144° 34'W
2144 m. Linear amplification. No filters.

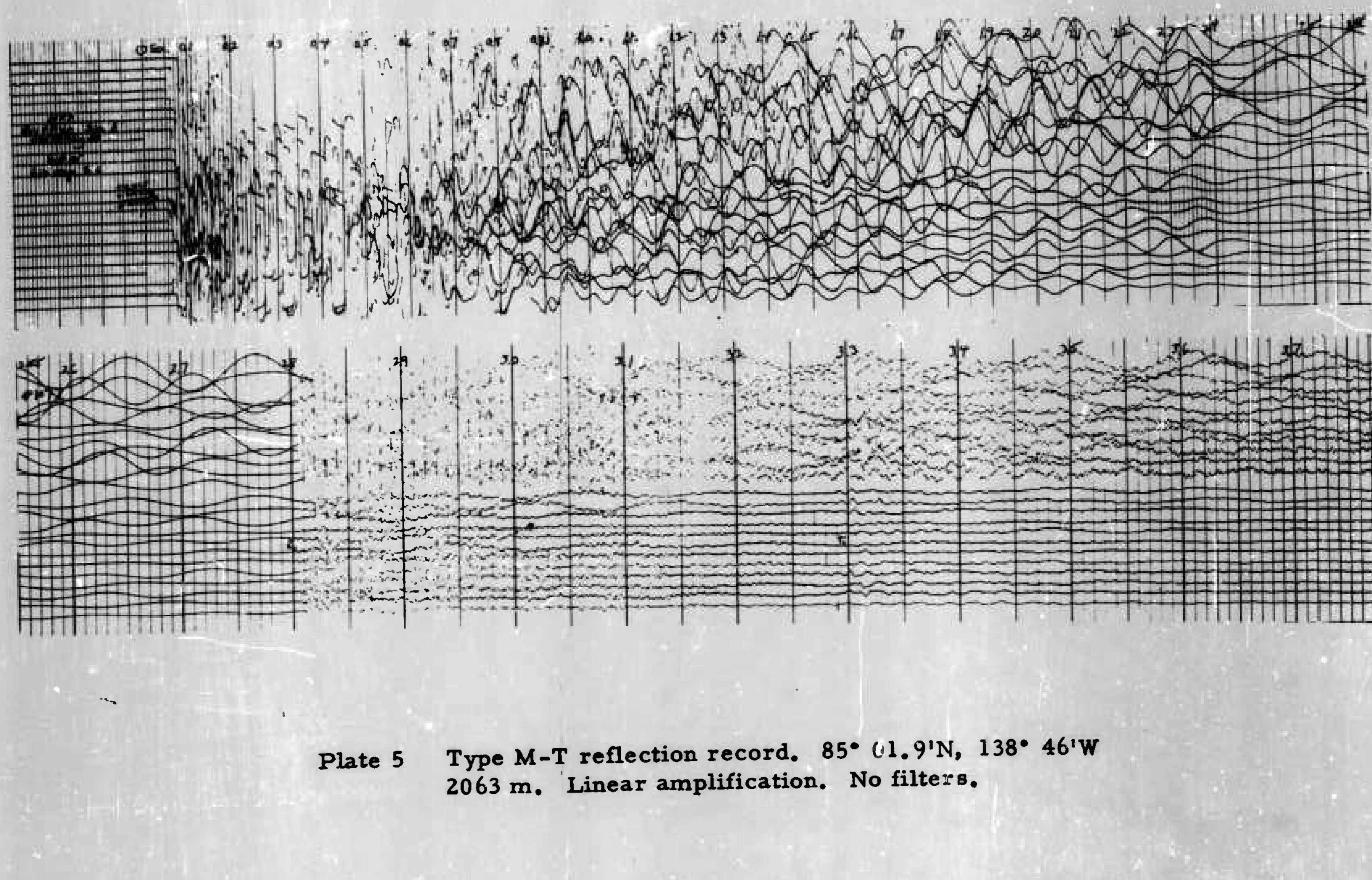


Plate 5 Type M-T reflection record. 85° 01.9'N, 138° 46'W
2063 m. Linear amplification. No filters.

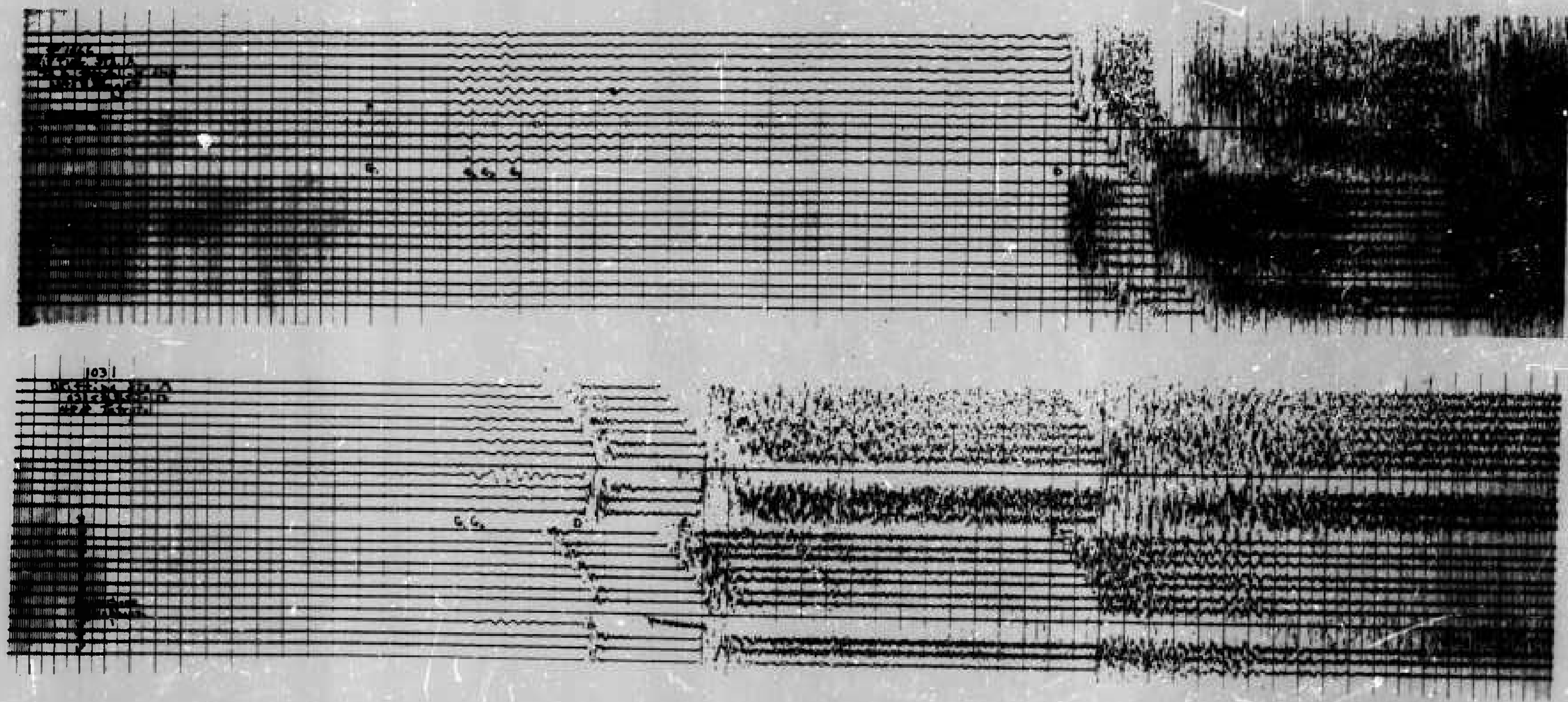


Plate 6 Refraction records. The upper record is from profile No. 5. The lower record is from profile No. [illegible]. Linear amplification. No filters. Late phases of the record, including the air wave, are not shown.

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